# Construction and Commissioning of the High Energy Resolution Spectrometer (HERS) for the Study of Highly Correlated Materials

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## INTRODUCTION

This endstation was designed to study highly correlated-materials, including the high temperature superconductors with unprecedented resolution. As many feel that the most useful clues to understanding these fascinating materials will come from angle-resolved photoemission data (ARPES) the 100 fold increase in momentum resolution afforded by the HERS endstation will provide many of the clues to understanding the High $T_c$ materials.

## THE ANALYZER

The electron energy analyzer is a commercial unit purchased from Gammadata-Scienta AB. As Fig. 1 demonstrates, the energy resolution from this instrument is excellent. Fig. 1A we display the photoemission spectra of the fermi-edge function from a polycrystalline gold sample at temperature of 10 K. With thermal broadening of 4.4*KT or 4 meV at 10 K, the combined analyzer and beamline energy resolution is 8 meV. Fig.1B is the photoemission spectrum of the Ar $3p_{3/2}$ core level taken using 25 eV synchrotron radiation from beamline 10.0.1.1. The full width at half maximum of the peak is 8 meV. Taking into account the natural line width and Doppler broadening of the Ar 3p line, the total contribution from the beamline and the analyzer is 3 meV

In addition to the excellent energy resolution, the analyzer also demonstrated very good angular resolution. When operating in the angular mode, the analyzer lens system focus changes so that the lens diffraction plane is at the entrance slit to the analyzer. This allows the two-dimensional focusing of the hemispheres to maintain the angle with which the electrons left the sample. Using the proper image-capturing equipment we can at one time collect and energy analyze electrons leaving the sample within a cone of ± 7° with 0.2 ° resolution. This angular resolution is an order of magnitude increase in resolution over previous equipment apparatus. In Fig. 2, we show the

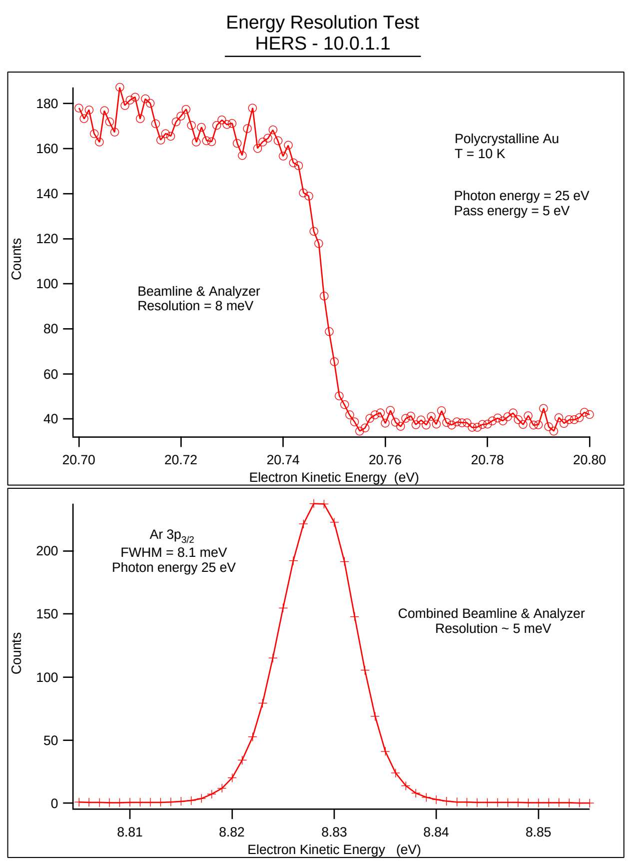


Fig. 1. Energy resolution demonstrated by the HERS analyzer and beamline 10.0.1.1. A. Au fermi-edge measured at 10 K using 25 eV photons. The combined analyzer and beamline resolution is 7 meV. B. Ar $3p_{3/2}$ photoemision line at 25 eV photon energy. The combined energy resolution here is 3 meV.

results of the angular mode testing. The electron source is a thin wire illuminated by 55 eV photons from the synchrotron beam. This wire is parallel to a slit array positioned 25 mm above it. The slits are 100 µm wide and spaced 500 µm center to center, which gives a spacing between slits of 1.3 degrees. This spectrum was collected using 5 eV pass energy. As can be see in the figure, the angular resolution is excellent even at kinetic energies approaching the pass energy. Fitting a Gaussian to the individual peaks gives an angular resolution of ± 0.15° when one accounts for the width of the source and width of the slit. While the intensity is uneven over several channels, we believe this is an artifact due to inhomogeneous graphite coating on the slit array.

An important feature of the endstation is the ability to rotate the analyzer about the incoming beam. The main chamber, where the electron energy analyzer is mounted rotates 120° about the incoming beam. Because the radiation from the storage ring is polarized in the plane of the ring, this rotation allows one to vary the polarization incident on the target from s to p while maintaining a constant emission angle from the sample. Two differentially pumped rotary seals mounted to the chamber allow the rotation while maintaining good vacuum. The chamber base pressure is less than 3x$10^{-11}$ torr and there is no appreciable pressure change when the analyzer is rotated.

## SAMPLE MANIPULATOR

The manipulator consists of two important parts. The first is the x, y, z stage. For this part we made use of existing technology and purchased a commercial mill table. The mill, while quite large, works very well in this application allowing very precise sample movements of 0.001” over the 37” of travel from the sample prep chamber to the analysis position in the main chamber. The sample polar rotation is accomplished by a differentially pumped rotary feedthrough to which the liquid helium cooled cryostat is mounted. The azimuthal rotation is cable driven through a rotary feedthrough. The rotational accuracy for both axes is 0.5°. With the LHe cooled cryostat the sample temperature can be controlled from 10 K to 450 K with better than one degree accuracy.

Also deserving of special mention is the sample transfer system. The reactive nature of the sample surface dictates that the experiments be performed at less than 5 x $10^{-11}$ Torr, in order to study surfaces that are representative of the bulk. Additionally, the samples cannot be baked. These two criteria require an excellent sample load lock

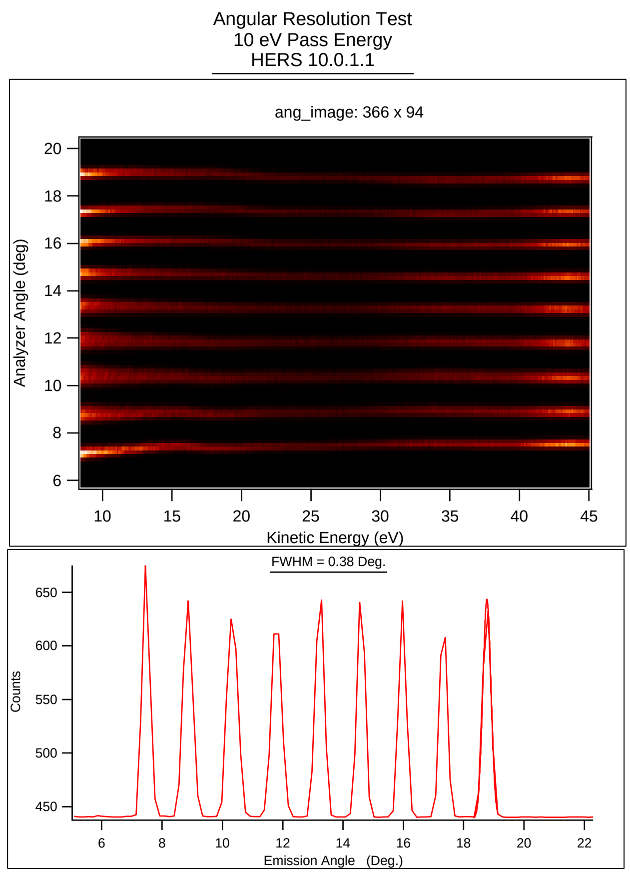


Fig. 2. The angular resolution of the HERS analyzer. The sample is a slit array of 100 µm wide slits spaced 500 µm center to center. The electron source is a 250 µm thick wire illuminated by 55 eV photons from beamline 10.0.1.1. Accounting for the angular size of the source and the slits, the demonstarted resolution is 0.3°. A the image of slit array collected by the analyzer . B. A narrow cut at 25 eV kinetic energy showing the angular resolution and uniform intensity across 12 degrees.

system.  The HERS system consists of three intermediate vacuum stages, which in practice allows the transfer of a fresh sample from atmosphere and on to the cryostat in 2 hours without baking while maintaining the prep chamber pressure of $4x10^{-11}$ torr.

**Future Direction**

With the initial commissioning of the endstation completed, work is now beginning on the high-$T_c$ superconductors.  Our initial experiments (detailed by Zhou in this compendium) are very encouraging.  We see the promise that a 100 fold increase in momentum resolution holds for a qualitatively new understanding of correlated materials.  In addition to the cuprates, we also plan to study the isostructural compounds nikelates, manganates and ruthenates.  These materials have their own equally fascinating physics, which the HERS will help to understand.

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